Design and Development of Six Degrees of Freedom Parallel Mechanism for the Purpose of Machining

Parallel Machining Bed

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***Abstract*— This research paper deals with a new concept of a 6 Degree of Freedom robotic machining bed. The robotic machining bed is an Arduino controller based a low cost, low power and easy to handle replacement of a CNC machine. Motion of bed in space consists of three translational motions in v forward, vertical and side directions and three rotational motions about these axis manipulated by the controller. The Paper details all aspects of development with complete methodology from paper design to final prototype testing results including its scope. The paper also contains details of the bed component used in its development which include linear actuators, Ball and socket joints, Universal joints and electric circuits. The bed has a stationary and a moving plate. Both plates are joined through six parallel variable length legs. The work piece is placed on the moving plate. The configuration of the robotic platform resembles the Stewart platform. The developed robotic bed is tested for position control of the center of the moving plate. The experimental results verify the design and show the suitability of the six degree of freedom robotic platform for a machining bed.**

Keywords— Machining, 6 dof machining bed, Stewart Platform, parallel robot

I. Introduction

The process of removing material from a work piece in order to get a desired shape is known as machining. Machining is a part of manufacture of metal products but can also be used on materials like ceramics, woods, plastics and composites. Turning, drilling and cutting are classified as three main processes of machining [1]. Varied categories of operations include shaping, boring, broaching and sawing. Examining machining processes closely divulges that a major holdup in reducing machining lead-time is the prolonged workpiece setup time. Since the direction of spindle axis is fixed either horizontally or vertically in conventional CNC machines, machining all five faces of a cubic workpiece [2]. Apart from current spindle technologies used for machining this paper elaborates the development of a six degree of freedom bed which can be used for the purpose of machining [3]. This developed six degree of freedom bed is known as Stewart Platform, which gives linear motion (lateral, longitudinal. Vertical) and as well as rotational motion (roll, pitch and yaw). In this mechanism the tool is fixed and all the movement is done by the bed [4]. Figure 1 shows the schematic of Stewart Platform. These Stewart Platforms have a high load capacity and give high accuracy [5]. Stewart Platforms have gained high attention from industrialists because of their vast applications [6]. Many commercial machining centers are developed by manufacturers using

Stewart Platform architecture [7, 8] but the literature lacks research in this area.

Materials and circuitry used for the development is discussed in section 2. Whereas tests done for Stewart Platform are discussed in section 3.

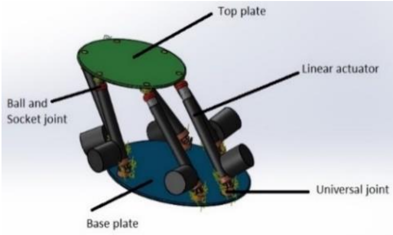

Fig.1: Schematic diagram of the parallel manipulator bed

II. Design and Analysis of Machining Bed

Mechanical design discussed may be used to analyze the performance measures such as, accuracy, positioning, repeatability and freedom from vibration. Stewart platform like manipulator is proposed for this research which consists of a rigid moving plate, connected to a fixed base through six independent legs [9]. The legs of Stewart Platform are identical kinematics chains, connecting the fixed lower platform and the movable top platform. The lengths of six linear actuators control orientation and position if the movable top plate which are driven by servo motors that connect it to the base. At the base end, each actuator is connected by a two-degree-of-freedom universal joint. At the end of moveable top plate, each actuator is attached with a three-degree-of-freedom ball-and-socket joint [10]. Thus, length of the legs is variable and they can be controlled discretely to control the motion of the moving platform. It exhibits characteristics of closed-loop mechanisms. Following assumptions were made to calculate different parameters for the platform,

- Movement of platform will be in six degrees only
- Lengths of legs will be same initially
- Outer workspace

Based on above mentioned assumptions workspace was calculated for the platform and different parameters for the linear actuators were calculated

A. Workspace

Reachable workspace can be defined as the collection of all points $\{x\ y\ z\}^T$ that are reachable by the manipulator in any orientation. For parallel robots workspace is limited due to following constraints:

i. Limitations on Mechanical Joints (Universal and Ball and Socket)
ii. Links interference
iii. Limited range of link lengths

The ability of the parallel robot to translate depends upon the orientation of the end effector. For this application of machining robot is moved in fixed orientation and rotates about a fixed point. So, three out of six coordinates of end effector will have constant value.

B. Link Parameters

Assumed that link lengths are same initially and all the rotations about X, Y and Z axis are zero each linear actuators can give length of 120mm. Velocity of each linear was calculated to be 12 mm/s.

Based on these requirements Parallel robot was developed for machining purpose.

III. Material Used to Develop a Machining Bed

The machining bed consists of ball and socket joints, universal joints, linear actuators, upper movable plate and lower fixed plate [11]. All these components are discussed in detail as follows.

A. Ball and Socket Joint

Ball and socket joints as seen in figure 1 are mounted on top plate. Figure 2 shows the schematic of ball and socket joint.

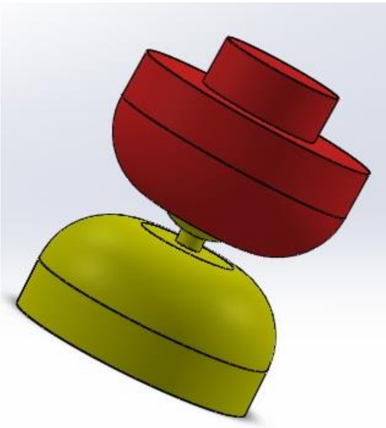

Figure 2: A model of Ball and Socket Joint

These ball and socket joints will give motion to bed in 3 degree of freedom. It is used in this platform to give upper platform motion in different axis at certain angles. Figure 3 shows ball and socket joint used for development of Stewart Platform practically.

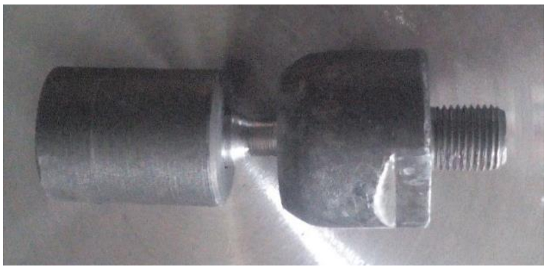

Figure 3: A Ball and Socket Joint

B. Universal Joint

From figure 1 it can be seen that universal joints are mounted on the fixed base plate of the platform. Universal joint allows the shaft to bend in any direction and are mostly used where there is rotary motion. Figure 4 shows the schematic of a universal joint.

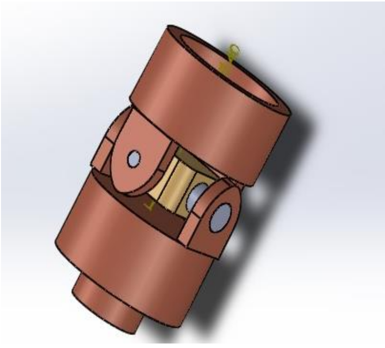

Figure 4: Schematic of a Universal Joint

These universal joints give motion to linear actuators in 2 degrees X axis and Y axis. Figure 5 shows a universal joint used in developing this platform physically.

Figure 5: A Universal Joint

C. Linear Actuators

an actuator that creates motion in a straight line, in contrast to the circular motion of a conventional electric motor is known as a linear actuator. This linear actuator acts as a kinematic link between fixed base plate and movable top plate [12]. Figure 6 shows a linear actuator mounted in Stewart Platform.

Figure 6: A linear Actuator

Each ball and socket joint, linear actuator and universal joint act as a leg of this parallel mechanism. Six linear actuators used will give different controlled lengths which will give motion to the upper plate in different degrees of freedom.

D. Plates

Base plate and movable top plate used for development of platform are made of iron. Having radius of 140mm and 100mm respectively.

IV. CIRCUITRY

This section presents the electronic circuitry used for actuator motor direction and speed control and the controller.

A. H-bridge

Six BJT based H-Bridges were used to derive motors. Circuit of H- Bridge is shown in figure 7.

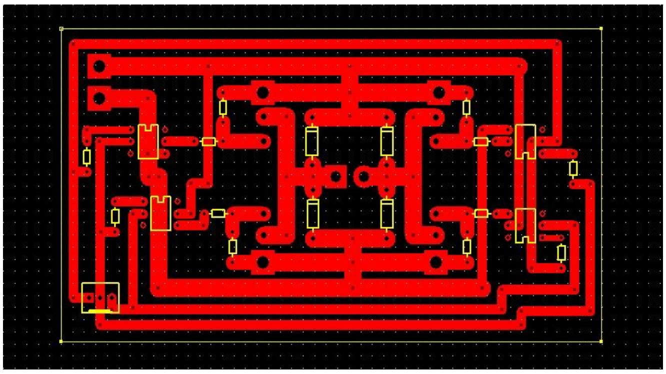

Figure 7: Circuit of H-bridge

Components required for H-Bridge are following

- 4N35 ouptocoupler
- TIP 147
- TIP 142

- Resistors 1kΩ, 10kΩ, 470Ω
- Diodes
- Connectors

Circuit shown in figure 7 is assembled using above mentioned components for hardware use. Figure 8 shows hardware of H-bridges.

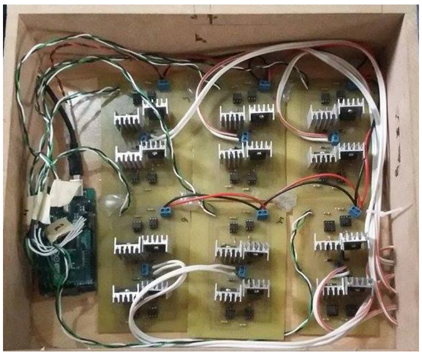

Figure 8: Hardware of H-Bridge

B. Arduino

Requirement for controller regarding this research was that it must have six I/O's for PWM (Pulse Width Modulation) control and twelve I/O's for motor control. To meet these requirements Arduino Mega was used. Figure 9 shows an Arduino Mega board.

Figure 9: Arduino Mega board [13]

Arduino Mega board is used to communicate instructions and control actions to the linear actuators. The control program describes the details of dimensions which need to be machined and defines coordinates accordingly. Then generate instructions to for the actuator motion.

V. Development of the Machining Bed

Using all the components mentioned in section 2 and section 3 Stewart Platform like machining bed was built physically. Figure 10 shows a physically developed Stewart Platform.

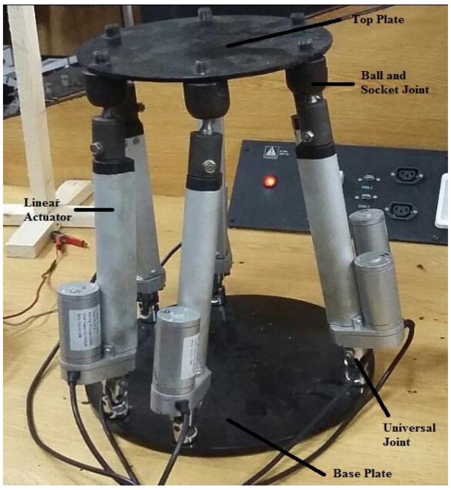

Figure 10: Developed Stewart Platform

The height of this Stewart Platform is 380mm. All the legs of platform may move simultaneously to give a six degree of freedom motion. This physically developed Stewart platform was tested for six DOF which is discussed in detail in next section.

VI. Tests

A. Test for Movement in Six Degrees of Freedom

After development, Stewart Platform was tested for motion in six DOF. Motion in different axes is explained in this section. When platform is moving in one axis than motion in other axes is constrained.

Figures 11 to 16 show motion of Stewart Platform in 6 Degrees of freedom.

Translation in Z-axis:

Figure 11: Translation of platform in Z-axis

Rotation in Z-axis:

Figure 12: Rotation of platform in Z-axis

Translation in X-axis:

Figure 13: Translation of platform in X-axis

Rotation in X-axis:

Figure 14: Rotation of platform in X-axis

Translation in Y-axis:

Figure 15: Translation of platform in Y-axis

Rotation in Y-axis:

Figure 16: Rotation of platform in Y-axis

From above figures it can be seen that developed Stewart Platform is capable of giving motion in different axis in different orientations.

B. Testing of Stewart Platform for Machining

Once Stewart Platform was tested for movement in six degrees of freedom then it was tested for machining purpose. Figure 17 shows the workpiece on which machining was done.

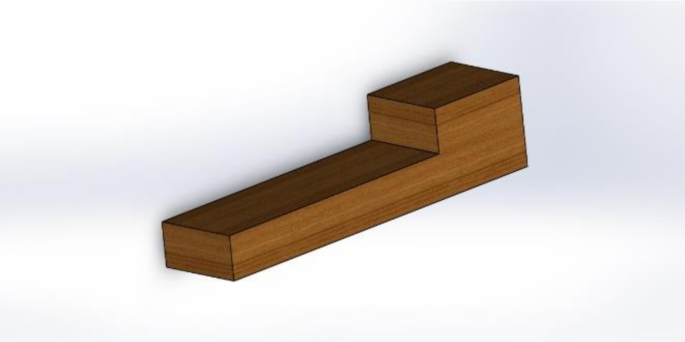

Figure 17: Workpiece used for Machining

Various tests were conducted on this wooden workpiece to verify application of Stewart platform in machining. Marker was taken as mimic tool and it was fixed on a stand. This workpiece was attached to the top plate of Stewart platform and test were done. Figure 18 shows a colleague of figures which show that how machining is being done on the workpiece.

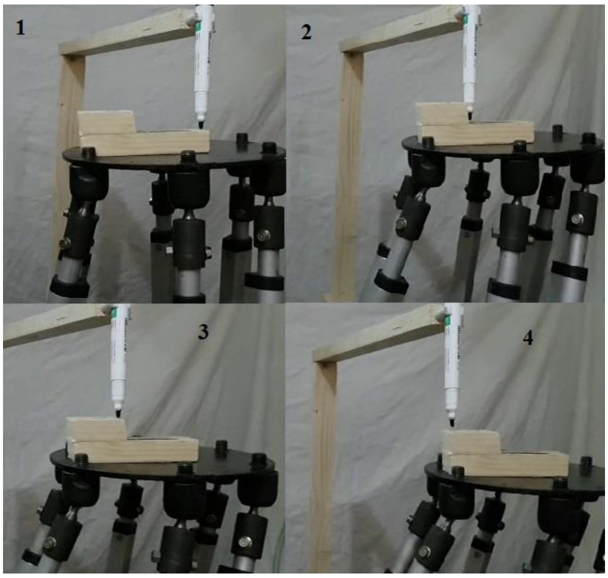

Figure 18: Machining being done on work piece

Form above figure it can be seen that developed Stewart Platform can be used for machining.

VI. Conclusion

As proposed above, Stewart Platform was developed and was tested for motion of a workpiece in six degrees of freedom. Tests were conducted to get motion in different orientations from the platform. When used for machining purpose, the workpiece was attached to the movable top plate and the tool was fixed. Coordinates of workpiece were given to the controller and in return controlled motion in desired axis and orientation was achieved. This proved the concept that a parallel mechanism can be used as a machining bed with multiple degrees of freedom.

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